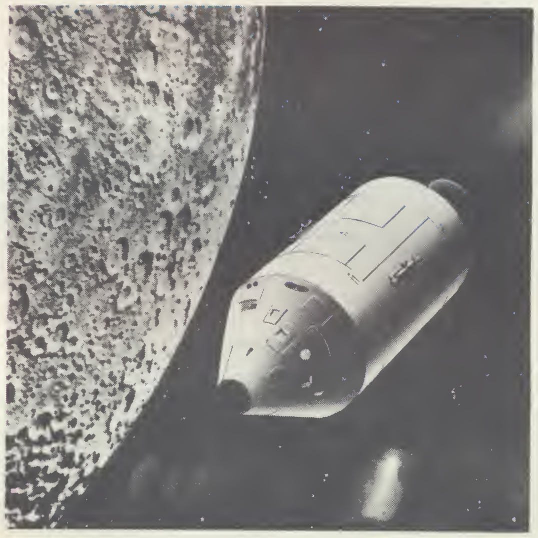
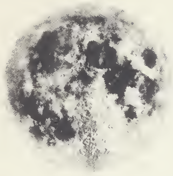
APOLLO GUIDANCE COMPUTER



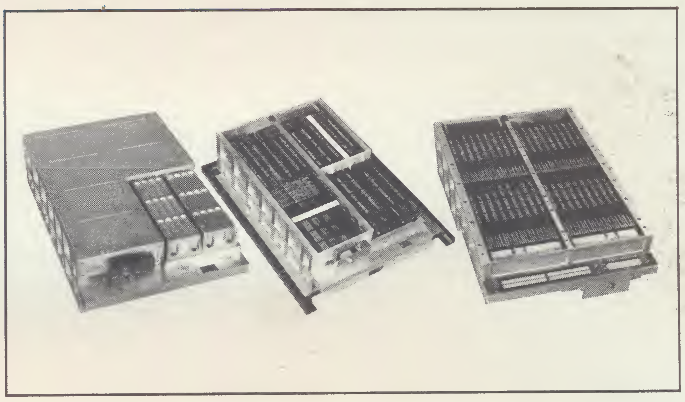
RAYTHEON

RAYTHEON COMPANY

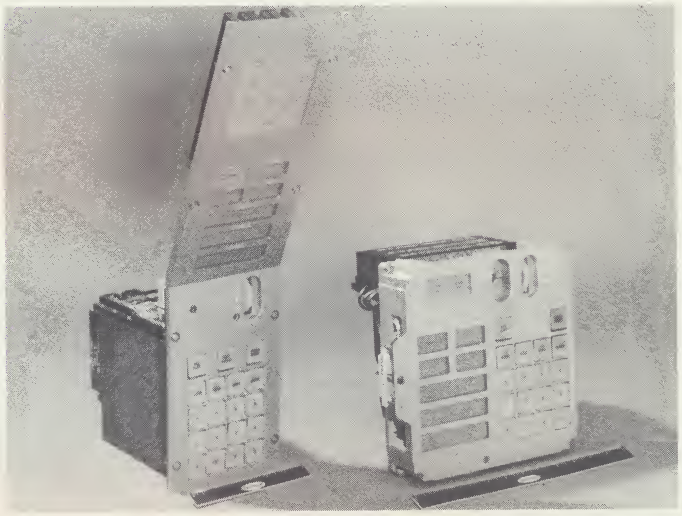
SPACE AND INFORMATION SYSTEMS DIVISION



APOLLO GUIDANCE AND NAVIGATION SYSTEM



APOLLO BLOCK I (SERIES 100)
Flight Computer currently in production for Manned and Unmanned Apollo Missions.



APOLLO DISPLAY AND KEYBOARD (DSKY)
Raytheon's Display and Keyboard is the visual and electronic link between the astronaut, the computer, and the spacecraft.

The Guidance, Navigation, and Control (GN&C) System to be provided the astronauts for the lunar exploratory and landing missions is a stellar-inertial system conceived by the Massachusetts Institute of Technology's Instrumentation Laboratory and developed by Raytheon, A. C. Spark Plug and Kollsman in support of MIT.

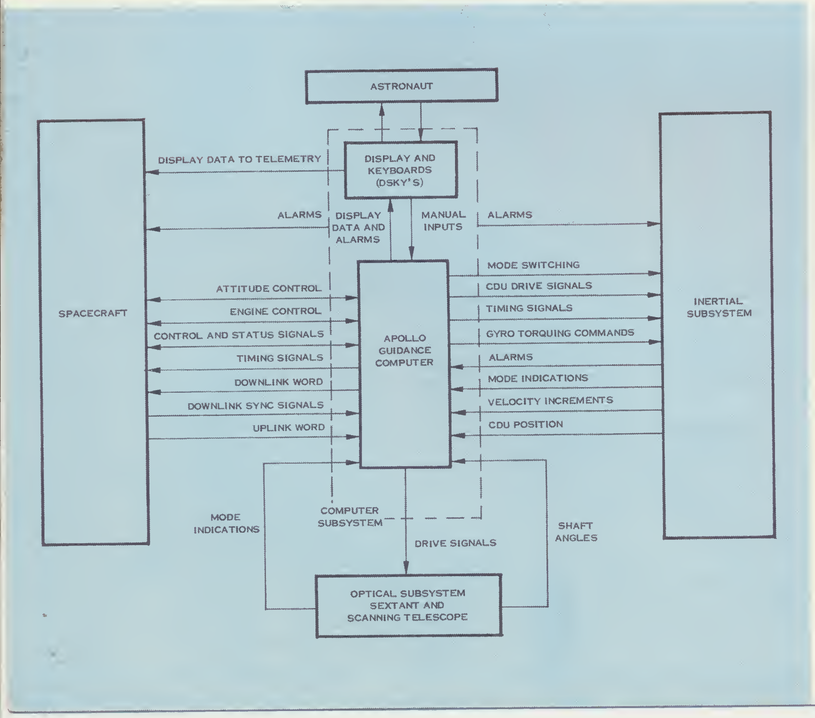
A general block diagram of the system is shown at lower left. The main subsystem includes the Computer by Raytheon, the Inertial Measurement Unit by A. C. Spark Plug, and the Optical Subsystem by Kollsman. A similar Guidance and Navigation System is under concurrent design for the LEM lunar landing vehicle by the same design and manufacturing team.

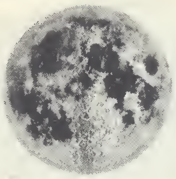
The Apollo Guidance Computer (AGC) and its associated display is the control and computation center of the GN&C System. Its control functions include aligning the Inertial Measurement Unit, positioning the Optical Subsystem, and orienting and stabilizing the Spacecraft (attitude control). In its role as a general purpose computer, the AGC solves guidance and navigation problems required for the round trip to the moon.

The AGC stores data defining the flight profile which the Spacecraft must assume to complete its mission. This data, composed of position, velocity and trajectory information, is used by the AGC to solve the flight and steering equations during orbital injection and mid-course guidance. The results of this solution determine the required magnitude and direction of thrust, and leave the computer as engine control signals.

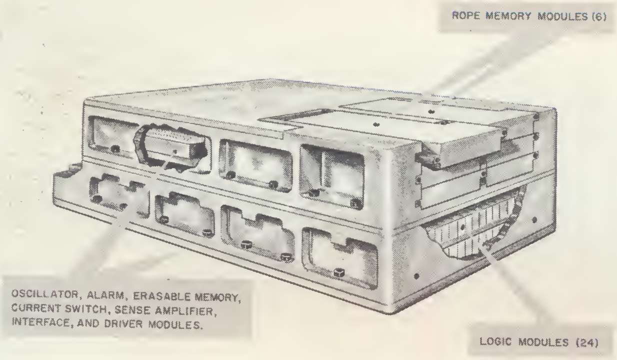
The Inertial Subsystem senses velocity changes which are accumulated within the AGC. The AGC can control the various Inertial Subsystem modes; e.g., in the coarse align mode, drive signals from the AGC are used to position the units in the Inertial Subsystem in order to set the desired gimbal angles in the Inertial Measurement Unit. The AGC receives mode indications and shaft angles from the Optical Subsystem during optical sightings and uses this information to calculate present position and to refine trajectory information. Optical Subsystem components are positioned automatically by drive signals supplied from the AGC.

The Display and Keyboard (DSKY) is the astronauts' control point for guidance and navigation of their vehicle. Maneuvering and navigation commands are processed and executed through the DSKY and AGC. The DSKY allows the astronauts to load information into the AGC to initiate various program functions and to perform tests on the AGC and the other subsystems on the Guidance and Navigation System. In addition, the DSKY indicates failures in the AGC, displays the program functions being executed by the AGC, displays specific data selected by the astronauts, and routes data from the AGC to the Spacecraft Telemetry System. In conjunction with the AGC, the DSKY also supplies alarm indication to the Spacecraft and to the Inertial Subsystem.





THE COMPUTER SYSTEM



APOLLO BLOCK II
Flight computer for future manned Apollo Missions.

The AGC is a parallel, single address, stored program, general purpose computer. The basic logic element is a dual 3-input NOR integrated circuit. Control pulses for instructions are synchronized by a 12-phase gating system operating at a 1 mcps clock speed. Arithmetic is performed in a binary, fixed-point, one's complement number system. The basic instructions and single-precision arithmetic operations are based upon a 15-bit word length.

A simplified block diagram of the AGC is shown below. The basic control section of the AGC is the sequence generator which processes priority requests and decodes instructions into sequences of control pulses to the other computer sections. The central registers are all directly addressable, thus providing important programming freedom.

The main program and constant memory is of core rope design. This fixed (read-only) memory contains 36,864 16-bit words. The memory cycle time is 11.7 μsec. The erasable (scratch pad) memory is a coincident current core memory with a 2,048 word (16-bit) capacity.

Additional features of the AGC include:

- Incremental Input Counters
- Programmed Pulsed Outputs
- Fixed Pulse Timing Outputs
- Program Controlled Interrupts
- Automatic Interrupts
- Serial Telemetry Input and Output Channels
- Automatic Fault Detection and Alarm
- Dual Display and Keyboard Capability
- Special Monitor and Test Circuitry

The organization of the AGC provides the flexibility important to redesign and/or modification for any specific application. For example, a special interface channel and associated channel registers provide great I/O flexibility. The address structure readily allows re-allocation of special and central registers, fixed memory, and erasable memory.

Other types of memories which will make higher computation speeds feasible and which will provide an alterable program capability are presently being evaluated.

PROGRAMMING CHARACTERISTICS

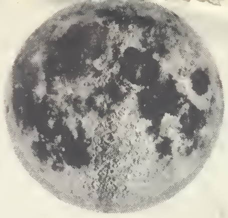
The Block II AGC presently under design will incorporate the instructions shown on the back page. These represent more than a tripling of the instruction set over the AGC currently in production. This increased instruction set provides the programming efficiency needed to perform the recently acquired attitude control function. All execution times are shown as multiples of the 11.7 μsec. memory cycle time (MCT).

The ability to address the special and central registers extends the power of the basic instructions. Also, addressing of specific registers provides the programmer with a number of "implied" address instructions; e.g., interrupt control instructions INHINT and RELINT (inhibit and allow interrupts) are obtained by TC 3 and TC 4 respectively.

In addition to the basic programmable instructions, there are a number of involuntary instructions utilized for counter incrementing, shifting and cycling, and for access to the AGC for external test and monitoring equipment.

An interpretive language program is utilized for processing multiple lists of pseudo-code instructions which are normally used for complex computations. The present interpreter has the capacity of 128 instructions and includes multiple precision and special vector operations. It provides a flexible structure for adding special arithmetic and control instructions to suit any application.

Organization	Parallel
Number System	1's complement
Power (Operating)	100 watts
Power (Standby)	10 watts
Clock Frequency	2 megacycles
Memory (Fixed)	36,864 words
Memory (Erasable)	2048 words
Word Length	15 bits plus parity
Volume	Approximately 1 cubic foot
Weight	Approximately 70 lbs
Add Time	24 μsec
Double Precision Add	36 μsec
Multiply Time	48 μsec
Double Precision Mult	480 μsec
Divide Time	84 μsec
Memory Density (NDRO)	3000 bits per cubic inch
Memory Density (DRO)	1000 bits per cubic inch



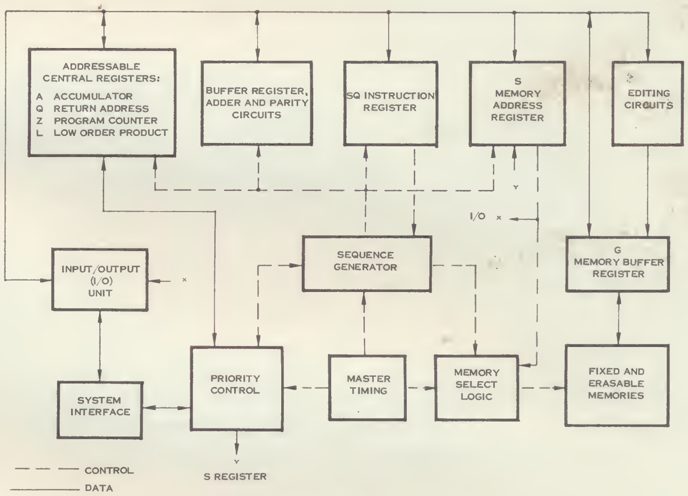
PROGRAMMING AIDS

A variety of standard multiple precision and trigonometric functions, including special routines to facilitate vector manipulations, are available within the library of subroutines.

The following special system programs to facilitate real-time operations are available.

- Executive control and priority system
- Input-Output control
- Display and Keyboard operation
- Error checking and diagnosis

Compilers and assemblers are available to assist the programmer in the preparation of programs. A simulator is available to assist in the debugging of programs early in their design.



AGC INSTRUCTION REPERTOIRE
(1 MCT = 11.7 μsec)

Execution Time (MCT)	Mnemonic Code	Basic Function
1	TC	Transfer Control
2	CCS	Count, Compare and Skip
1	TCF	Transfer Control to Fixed
3	DAS	Double Add to Storage
2	LXCH	Exchange (L and Operand)
2	INCR	Increment
2	ADS	Add to Storage
2	CA	Clear and Add
2	CS	Clear and Subtract
2	INDEX	Index Next Instruction
2	TS	Transfer to Storage
3	DXCH	Double Exchange
2	XCH	Exchange
2	AD	Add
2	MSK	Mask

Extracode instructions. These must be preceded by an EXTEND (special case of TC).

2	READ	Read Channel
2	WRITE	Write Channel
2	RAND	Read and Mask
2	WAND	Write and Mask
2	ROR	Read and Superimpose
2	WOR	Write and Superimpose
2	RXOR	Read and Invert
6	DV	Divide
2	MSU	Modular Subtract
2	QXCH	Exchange (Q and Operand)
2	AUG	Augment
2	DIM	Diminish
3	DCA	Double Clear and Add
3	DCS	Double Clear and Subtract
2	NDXX	Index Extracode Instruction
2	SU	Subtract
3	MP	Multiply
1 or 2	BZF	Branch Zero to Fixed
1 or 2	BZMF	Branch Zero or Minus to Fixed

OTHER APPLICATIONS

The AGC is of modular plug-in construction throughout, using all welded circuitry, and using techniques and quality assurance methods developed largely on the Polaris Mark 2 Guidance Program—another successful venture of the Raytheon-MIT team. Its high component density and automated manufacturing techniques facilitate modification to a wide variety of both special and general purpose uses. It has been designed and constructed throughout to NASA's unparalleled reliability requirements, and has an inherent flexibility enabling utilization with a wide range of peripheral equipments.

Raytheon's Digital Systems staff welcomes your inquiries concerning design and application of this and similar equipment to your needs, and our staff can supply a wide range of analytical, design, and manufacturing talent to your programs' computer needs, be they airborne, spaceborne, or on the ground.

For additional information, write or call:

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